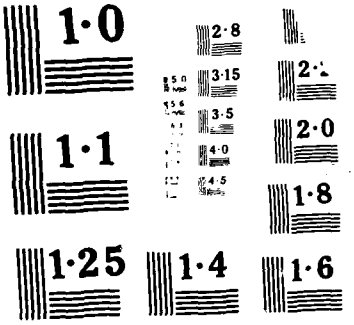
AD-A190 854 TIME-DOMAIN FREQUENCY-SELECTIVE OPTICAL MEMORIES: A STUDY OF THE BASIC ME..(U) HARVARD UNIV CAMBRIDGE MA DIV OF APPLIED SCIENCES T W MOSSBERG 21 DEC 87 1/1

UNCLASSIFIED ARO-19903.14-PH DAAG29-83-K-0040 F/G 9/5 NL


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·8
3·15
3·5
4·0
4·5

MASTER COPY - FOR REPRODUCTION PURPOSES

(2)

AD-A190 854

DTIC FILE COPY

REPORT DOCUMENTATION PAGE

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

3 DISTRIBUTION / AVAILABILITY OF REPORT

Approved for public release; distribution unlimited.

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

4 PERFORMING ORGANIZATION REPORT NUMBER(S)

5 MONITORING ORGANIZATION REPORT NUMBER(S)

ARO 19983.14-PH

6a. NAME OF PERFORMING ORGANIZATION

HARVARD UNIVERSITY

6b OFFICE SYMBOL (If applicable)

7a. NAME OF MONITORING ORGANIZATION

U. S. Army Research Office

6c. ADDRESS (City, State, and ZIP Code)

Cambridge, Massachusetts 02138

7b. ADDRESS (City, State, and ZIP Code)

P. O. Box 12211
Research Triangle Park, NC 27709-2211

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

U. S. Army Research Office

8b. OFFICE SYMBOL (If applicable)

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

DAAG29-83-K-0040

8c. ADDRESS (City, State, and ZIP Code)

P. O. Box 12211
Research Triangle Park, NC 27709-2211

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11 TITLE (Include Security Classification)

Time-Domain Frequency-Selective Optical Memories: A Study of the Basic Mechanisms and Potential Systems

12 PERSONAL AUTHOR(S)

Thomas W. Mossberg

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 2/14/83 TO 9/30/87	1987, December 21	10

16 SUPPLEMENTARY NOTATION

The view, opinions and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

17 COSATI CODES		
FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Optical Memory
Optical Processing
Non-Linear Optics

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Fundamental principles associated with a new non-linear optical approach to constructing ultra-high speed, high density, optical memories have been studied in a four-year ARO research contract. Basic feasibility of the approach has been established. Non-linear optical approaches to optical processing, phase-conjugation, and pulse compression were also investigated.

DTIC
ELECTE
FEB 02 1988
S D
H

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT

☐ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION

Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE (Include Area Code)

22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

Time-Domain Frequency-Selective Optical Memories: A Study of the Basic Mechanisms and Potential Systems

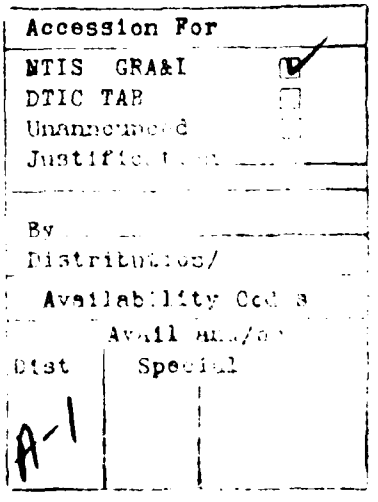
Final Report

Author: Thomas W. Mossberg
Department of Physics
University of Oregon
Eugene, Oregon 97403
(503) 686-4779
(formerly of Harvard University)

U. S. Army Research Office

Contract Number: DAAG29-83-K-0040

Harvard University
Division of Applied Science
Cambridge, Massachusetts 02138



Approved for Public Release;
Distribution Unlimited

The view, opinions, and/or findings contained in this report are those of the author and should not be construed as an official department of the army position, policy, or decision, unless so designated by other documentation.

88 1 27 086

I. Problem Studied

A. Introduction

Some years ago, the present author proposed[1] a coherent optical means of storing time-dependent optical signals, potentially on a permanent basis, in absorber materials that display inhomogeneous optical line broadening. It was, in essence, pointed out that such materials can act as spectrum analyzers and record the spectrum of an intricately structured optical pulse, and then following coherent excitation produce a duplicate of the pulse. It was suggested that this process could provide the basis for the development of an entirely new class of optical storage devices possessing both ultrahigh speed (> 10 Ghz) and ultrahigh data storage density. It was calculated that a bit of optical information could be stored for every 10,000 absorber atoms in the storage material. An extensive experimental and theoretical effort aimed at the analysis of this process was thereafter proposed to the Army Research Office. It was this proposal that served as the basis of the present contract. For a general introduction to the phenomenology associated with the approach to optical storage studied, see the Appendix.

B. Gas Phase Memory Experiments

The first phase of our program was to thoroughly examine the optical physics associated with the memory effect proposed. In order to minimize material-related complications, this work was undertaken in a gas-phase sample of atomic Ytterbium, which it turns out constitutes an extremely simple material from the prospective of analysis. Such samples are of course useless in regards to long term storage, but perfect for helping us to learn about the basic mechanisms involved in the storage phenomena.

A number of experiments[2-7] were conducted. In the course of them, we verified most of the predictions originally made[1], but importantly learned many new things about the proposed storage process. We determined a number of different experimental approaches that guaranteed the faithful storage and recall of data encoded on optical signals. This work is detailed in references 2 through 7. Throughout this work we were limited to relatively low ($\simeq$25 MHz) storage and recall bandwidths because of equipment limitations.

C. Optical Data Processing by Coherent Optical Means

In the course of our work, we discovered that the same optical process that gives rise to the memory effect can be employed to generate signals representing cross-correlations, auto-correlations, and convolutions of optical input pulses. As in the case of the memory application, indications are that extremely large bandwidth pulses can be accommodated. In experiments leading to several publications[8-10], we analyzed and demonstrated the effects. A patent (4,670,854) based on this effect was obtained.

D. Coherent Transient Effects Generated by Frequency-Swept Optical Pulses

One of the memory effect experiments required us to develop a frequency-chirped (swept) laser source. Having done so, we also employed it to generate coherent transient optical signals. Interesting new effects were observed.[11,12] It was found that photon echoes having durations determined by the total bandwidth rather than the duration of the excitation pulses are produced. These echoes are very intense, containing a sizable fraction of the energy contained in the excitation pulses. The mechanism by which they are produced is similar to that which operates in femtosecond pulse compression. In the echo case, however, optical energy is temporarily stored as a material excitation and re-emitted as a short pulse. Echo compression may serve as a means of compressing long (micro to millisecond) pulses to short intense nanosecond pulses.

E. Time-Delayed Phase Conjugation

Yet another application of the memory process is the storage and delayed reproduction of phase conjugated images. This has been experimentally demonstrated and published.[13]

F. Memory Studies in Solid-State Samples

Practical applications of time-domain optical memories will have to involve solid-state storage materials. In the final stages of our work, we began to study a solid-state material, i. e. $Eu^{3+}:Y_2O_3$. For the memory process to function in this material, it is necessary to work at cryogenic temperatures (less than about 10K). We completed a comprehensive study of the properties of this material as a function of temperature,[14] and we did in fact demonstrate the memory effect.[15] Storage times of more than 10 hours were obtained. Further work on appropriate solid-state materials is needed. On the basis of existing knowledge, it is not clear how high in

temperature one can eventually work.

References

1. T. Mossberg, Opt. Lett. **7**, 77 (1982).

2. N. W. Carlson, L. J. Rothberg, A. G. Yodh, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **8**, 483 (1983).

3. N. W. Carlson, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **9**, 232 (1984).

4. N. W. Carlson, Y. S. Bai, W. R. Babbitt, and T. W. Mossberg, Phys. Rev. A (Rapid Communications) **30**, 1572 (1984).

5. N. W. Carlson, W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, J. Opt. Soc. Am. **B1**, 506 (1984).

6. N. W. Carlson, W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, J. Opt. Soc. Am. **B2**, 908 (1985).

7. Y. S. Bai, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **11**, 724 (1986).

8. Y. S. Bai, W. R. Babbitt, N. W. Carlson, and T. W. Mossberg, Appl. Phys. Lett. **45**, 714 (1984).

9. W. R. Babbitt and T. W. Mossberg, Appl. Opt. **25**, 962 (1986).

10. W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, Proceedings of SPIE, **639**, (April 1986).

11. Y. S. Bai and T. W. Mossberg, Appl. Phys. Lett. **45**, 1269 (1984).

12. Y. S. Bai and T. W. Mossberg, Opt. Lett. **11**, 30 (1986).

13. N. W. Carlson, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **8**, 623 (1983).

14. W. R. Babbitt, A. Lezama, and T. W. Mossberg, (manuscript in preparation).

15. W. R. Babbitt and T. W. Mossberg, (submitted for publication in Opt. Commun.).

Supported Publications

Storage and time reversal of light pulses using photon echoes, N. W. Carlson, L. J. Rothberg, A. G. Yodh, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **8**, 483 (1983).

Field-inhibited optical dephasing and shape-locking of photon echoes, N. W. Carlson, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **9**, 232 (1984).

Temporally programmed free-induction decay, N. W. Carlson, Y. S. Bai, W. R. Babbitt, and T. W. Mossberg, Phys. Rev. A (Rapid Communications) **30**, 1572 (1984).

Shape locking of photon echoes, N. W. Carlson, W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, J. Opt. Soc. Am. **B1**, 506 (1984).

Spectrally ordered Zeeman coherences and optical pulseshape storage, N. W. Carlson, W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, J. Opt. Soc. Am. **B2**, 908 (1985).

Coherent transient optical pulse shape storage/recall using frequency-swept excitation pulses, Y. S. Bai, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **11**, 724 (1986).

Real-time optical waveform convolver/cross-correlator, Y. S. Bai, W. R. Babbitt, N. W. Carlson, and T. W. Mossberg, Appl. Phys. Lett. **45**, 714 (1984).

Mixed binary multiplication of optical signals by means of convolution in an inhomogeneously broadened absorber, W. R. Babbitt and T. W. Mossberg, Appl. Opt. **25**, 962 (1986).

Convolution, correlation, and storage of optical data in inhomogeneously broadened absorbing materials, W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, Proceedings of SPIE, **639**, (April 1986).

Photon echo optical pulse compression, Y. S. Bai and T. W. Mossberg, Appl. Phys. Lett. **45**, 1269 (1984).

Experimental Studies of photon-echo pulse compression, Y. S. Bai and T. W. Mossberg, Opt. Lett. **11**, 30 (1986).

Storage and phase conjugation of light pulses using stimulated photon echoes, N. W. Carlson, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. **8**, 623 (1983).

Optical homogeneous linewidths, ground-state grating decay, and hyperfine splittings in europium-doped yttrium oxide, W. R. Babbitt, A. Lezama, and T. W. Mossberg, (manuscript in preparation).

Time-domain frequency-selective optical data storage in a solid-state material, W. R. Babbitt and T. W. Mossberg, (submitted for publication in Opt. Commun.).

Scientific Personnel

1. Dr. W. R. Babbitt (received Ph. D. fall 1987, currently at Boeing High Tech Center).

2. Dr. Y. S. Bai (received Ph. D. spring 1987, currently at Stanford University).

3. Dr. A. G. Yodh (received Ph. D. summer 1986, currently at AT&T Bell Labs).

4. Dr. N. W. Carlson (currently at Sarnoff SRI research labs).

5. Dr. A. Lezama (currently at the University of Oregon).

6. Dr. T. W. Mossberg (currently at the University of Oregon).

Appendix

Time-Domain Frequency-Selective Optical Memories

I. Concept

Over the last few years, a radically new approach to optical data storage has been proposed and subjected to preliminary investigation in the author's laboratory. This approach is based on the fact that certain optical materials can be induced to store a *spectral image* of an information carrying light beam and later be stimulated to reconstruct the light beam and its encoded information. For brevity, we refer here to optical memories based on this mechanism as *time-domain* optical memories.

There are several reasons why this approach to optical data storage is of technological interest:

1. Input and output bandwidths are in principle limited only by the inhomogeneous absorption bandwidth of the storage material. In most systems studied to date, this limiting bandwidth is 10 Gigahertz or greater.

2. Many data bits can be encoded at each spatial location of the storage material. Hence, data storage densities can be very large. The present type of optical memory will in principle be capable of achieving storage densities (bits/square centimeter) several orders of magnitude greater than is possible with traditional surface modification approaches to optical data storage.

3. Optical signals are input and optical signals are directly output. Optical-electrical interfaces are in principle unnecessary.

In a simple implementation, time-domain storage and retrieval of information occurs as follows: First, the storage location is illuminated by a short pulse. Immediately thereafter, a data encoded beam is made incident on the storage location. This beam must be of limited duration and data content. These limits will be discussed below. Once the data beam is turned off, the storage process is complete, and the material has recorded the Fourier transform of the data beam. To recall the information stored, the material is simply illuminated by a short read pulse. Following this read pulse, the material emits an optical signal which is the time-delayed duplicate of the original data encoded beam. In typical cases, one can expect the output signal to be about one percent as intense as the input data beam.

There is at present one principal disadvantage to time-domain storage of optical data. In order for known materials to properly record the Fourier transform of the information beam, they must be cooled down to the range of 4 to 20 degrees Kelvin. For some applications, such as personal computers, this is a serious disadvantage indeed, but in the case of high performance systems where either high speed or high storage density are important, the disadvantage is not so serious. Commercial refrigerators capable of thousands of hours of unattended 10 K operation are available for a few thousand dollars.

II Mechanism

A number of papers in the published literature[1-4] have appeared in the last few years describing the nonlinear optical process that serves as the basis for time-domain memories. For a detailed discussion of the optical physics involved, the reader should refer to those papers and others referenced therein. Only a relatively limited discussion will be presented here.

The time-domain method is based on the existence of optical materials that display inhomogeneous optical broadening. In these materials, individual absorber atoms display very sharp optical absorption resonances, but because of site inhomogeneities in the material, atoms at microscopically different spatial locations resonate at different frequencies. The material is therefore characterized by two frequency widths. One, the inhomogeneous absorption width, $\Delta\nu_i$, represents the frequency interval over which individual atoms are spread. The other, the homogeneous absorption width, $\Delta\nu_h$, represents the absorption width of individual absorber atoms. For the present purposes, $\Delta\nu_h$ can be taken to be the same for all atoms. In cases where $\Delta\nu_i >> \Delta\nu_h$, the material resembles a spectrum analyzer in that it has the capacity to respond independently to optical Fourier components over the bandwidth $\Delta\nu_i$ with frequency resolution $\Delta\nu_h$. From standard Fourier analysis, it follows that the material can record a Fourier transform in sufficient detail to represent a temporal input signal containing

$$N = \frac{\Delta\nu_i}{\Delta\nu_h}$$

data bits.

The mechanism of storage can be understood as follows: The first pulse sensitizes the material by creating an optical coherence over the entire bandwidth of the data beam. The data beam then interferes with the existing optical coherence with the result that the population transferred out of the ground state of the material into the excited state is proportional to the data beam's Fourier transform. In the absence of the sensitizing pulse, the population transferred is proportional to the square of the data beam's Fourier transform. Only in the former case is the temporal structure of the data beam faithfully recorded by the inhomogeneous absorber.

When the excited state of the material decays several things may happen to prevent the loss of stored information. In the simplest case, several levels exist in the ground state and the excited-state population does not decay to them in the same proportion as it was pumped out of them. Thus as long as the ground-state sublevels are stable, an image of the data beam's Fourier transform remains in the material. This realization of long term storage may be referred to as optical-pumping storage, and in systems where optical pumping is the primary long term storage mechanism, storage times on the order of 24 hours have been demonstrated. Substantially longer optical-pumping storage times may be available in some materials.

Other more stable and hence technologically useful means of realizing long term storage utilize photochemistry to react away the excited-state population before it can decay back to the ground state. Analyses of known materials indicate that essentially permanent storage should be possible using photochemically active materials. Such materials also hold the promise of retaining stored information at elevated temperatures.

A temporal duplicate of the data beam can be created by uniform optical excitation of the stored Fourier transform. It can be shown,[1,2] that the light coherently emitted by a storage material after excitation by a short optical pulse possesses a temporal structure determined by the Fourier transform of the storage material's absorption profile. When the Fourier transform of a data beam is encoded into that absorption profile, it follows that the material-generated output signal will have the same temporal shape as the data beam. Analysis shows that only 10,000 optically active atoms need be present in the storage material for each stored data bit in order achieve acceptable signal-to-noise ratios in the output signal. The maximum number

of bits that can be stored at one spatial location is thus given by N as defined above, provided that enough atoms are present in the material to produce a detectable signal.

III The Challange

In order for the process described above to find wide application suitable storage materials must be found. The optimum storage material will have a very small value of $\Delta\nu_h$ (preferably in the KHz to MHz range) and a large value of $\Delta\nu_i$ (perferably greater than one GHz). Phonon-mediated broadening of $\Delta\nu_h$ should be small so that the material will be useful at high temperatures. Irradiation of the material in its excited-state should cause a very rapid photochemical transformation of the material into a species whose spectrum does not appreciably overlap the storage transition of the original material. Ideally, this photochemical transformation should be reversible. Ideally the ground and excited states of the storage material should consist of a single level. Degeneracy of these levels is not important, but the existence of many closely spaced levels may result in interference effects that distort the stored information. Finally, the storage material should have a macroscopic physical structure consistent with the fabrication of suitably shaped storage devices, e. g. thin disks. Very little spectroscopic, photochemical, or materials work has been undertaken to date whose objective has been to identify materials well suited for use in devices or systems utilizing the optical process described.

References

1. T. W. Mossberg, Opt. Lett. 7, 77 (1982).

2. W. R. Babbitt, Y. S. Bai, and T. W. Mossberg, Proceedings of SPIE vol. 639 (April 1986).

3. Y. S. Bai, W. R. Babbitt, and T. W. Mossberg, Opt. Lett. 11, 724 (1986).

4. W. R. Babbitt and T. W. Mossberg, submitted to Opt. Commun.

END

DATE

FILMED

5-88

DTIC